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Vaddadi, Bhavana ; Bieser, Jan ; Pohl, Johanna ; Kramers, Anna

Abstract: Through virtual presence, information and communication technology (ICT) allows employees to work from places other than their employer's office and reduce commuting-related environmental effects (telecommuting). Working from a local co-working space, as a form of telecommuting, has the potential to significantly reduce commuting and is not associated with deficits of working from home (e.g. isolation, lack of focus). However, environmental burden might increase through co-working due to the infrastructure required to set-up and operate the co-working space and potential rebound effects. In this paper, we (1) develop a framework of direct and indirect environmental effects of co-working based on a well-known conceptual framework of environmental effects of ICT and, (2) apply the framework to investigate the case of a co-working living lab established in Stockholm. Based on interviews and surveys conducted with co-workers in the living lab and infrastructure data of the co-working space, we roughly estimate associated energy impacts. Results show that energy requirements associated with operating the co-working space can counterbalance commute-related energy savings. Thus, in order to realize energy savings co-working should be accompanied with additional energy saving measures such as a net reduction of (heated) floor space (at the co-working space, at the employer's office and the co-workers home) and use of energy-efficient transport modes.

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Towards a conceptual framework of direct and indirect environmental effects of co-working

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ABSTRACT

Through virtual presence, information and communication technology (ICT) allows employees to work from places other than their employer's office and reduce commuting-related environmental effects (telecommuting). Working from a local co-working space, as a form of telecommuting, has the potential to significantly reduce commuting and is not associated with deficits of working from home (e.g. isolation, lack of focus). However, environmental burden might increase through co-working due to the infrastructure required to set-up and operate the co-working space and potential rebound effects. In this paper, we (1) develop a framework of direct and indirect environmental effects of co-working based on a well-known conceptual framework of environmental effects of ICT and, (2) apply the framework to investigate the case of a co-working living lab established in Stockholm. Based on interviews and surveys conducted with co-workers in the living lab and infrastructure data of the co-working space, we roughly estimate associated energy impacts. Results show that energy requirements associated with operating the co-working space can counterbalance commute-related energy savings. Thus, in order to realize energy savings co-working should be accompanied with additional energy saving measures such as a net reduction of (heated) floor space (at the co-working space, at the employer's office and the co-workers home) and use of energy-efficient transport modes.

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CCS CONCEPTS

•Social and professional topics~ Professional topics~ Computing and business~ Computer supported cooperative work •Applied computing~ Physical sciences and engineering~ Earth and atmospheric sciences~ Environmental sciences •Applied computing~ Physical sciences and engineering~ Telecommunications

KEYWORDS

ICT, co-working, telecommuting, energy consumption, commuting, flexible workplace

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1 INTRODUCTION

As cities continue to expand, people have started to move further away from city centers due to housing shortages and ever-increasing rents making commuting a physical and mental burden. Due to an often unreliable transportation system and heavy dependence on private vehicles, millions of people spend long hours commuting to and from work [1].

In 2011, roughly 38% of commuters in Stockholm were using private vehicles to commute to and from work while 25% used public transport [2]. In addition, car ownership and vehicular travel is ever increasing [3]. Besides its environmental impacts, commuting causes congestion during peak hours and has significant effects on individuals' well-being [4]. Hence, there is a dire need to adopt sustainable travel practices.

Information and communication technology (ICT) has transformed our existing patterns of production and consumption with consequences for the environment [5], [6] [7], [8]. Telecommuting, working remotely and collaborating with colleagues and partners by means of ICT, has the potential to reduce commute-related environmental impacts. A specific case of telecommuting centers are co-working (CW) spaces. CW "describes any situation where two or more people are working in the same place together, but not for the same company" [9, p. 3]. CW spaces are "shared workplaces utilized by different sorts of knowledge professionals […] working in various degrees of specialization in the vast domain of the knowledge industry" [10, p.194]. CW holds the potential to significantly reduce environmental impacts associated with commuting and is not associated with deficits of working from home (e.g. isolation, lack of focus). In order to realize these benefits, the choice of location of the CW space is in particular critical [11], [12],[13]

However, CW can also increase environmental burdens, for example through required infrastructure to set-up and operate the CW space. It can also lead to rebound effects, if employees spend time and money saved on commuting on other activities, goods and services that are associated with environmental impacts [14]. In order to draw more specific conclusions about whether CW can contribute to an overall reduction in resource consumption, and which factors are particularly relevant, a more precise analysis is necessary [11], [15], [16], [17]

One approach that has gained momentum in sustainability research is to test potentially sustainable innovations in living labs [18]. In living labs, data can be collected in a real-life setting and later be used for environmental assessment [19]. Within Mistra SAMS, a research project on sustainable transport in Sweden, a living lab CW space has been set up in the south of Stockholm (in the suburb Tullinge) and is in operation since January 2019. As of February 2020, out of 60 recruited participants, about 44 employees who live close to the CW space regularly work from there and can potentially avoid lengthy commutes to their employers' offices.

In this paper, we (1) develop a conceptual framework of the diverse environmental impacts of CW, and (2) apply the framework to investigate environmental impacts associated with the CW living lab in Stockholm. Thereby, we provide a systematic overview of potential positive and negative environmental impacts of CW. We hope this can provide first insights on environmental impacts of CW and stimulate further research on CW and other promising ICT applications, which is required to harness the potential to avoid environmental burdens and mitigate negative impacts of increasing ICT use.

The paper is organized as follows: Materials and methods are described in Section 2. The conceptual framework of environmental effects of CW is presented in Section 3, followed by the application of the framework to the CW case in Stockholm in Section 4. We end with a discussion and conclusion and identify potential for future research in Section 5.

2 MATERIAL AND METHODS

To develop a conceptual framework reflecting the environmental effects of CW, we use the framework of environmental effects of ICT by Hilty and Aebischer [8] and adapt it to the specific case of CW. The well-known and frequently applied taxonomy of environmental effects of ICT was introduced by Berkhout and Hertin [6] at first and has been revised several times since then [8], [16], [17]. The framework distinguishes three layers of environmental effects of ICT:

1. *Direct environmental* effects through production, use and disposal of ICT
2. *Enabling effects* of ICT use through the application of ICT also in other sectors (the effects result from changes in production and consumption patterns)
3. *Systemic impacts* through ICT-induced changes of existing socio-economic structures and institutions

This framework is useful to investigate the specific case of CW for the following reasons:

- CW is a specific use case of ICT as explained in the introduction.
- CW requires production, operation and disposal of infrastructures (e.g. CW space, ICT equipment), processes which cause environmental impacts (layer 1).
- CW can change existing production and consumption patterns (e.g. avoiding work-related travel or changing collaboration methods among colleagues – layer 2).
- CW can fundamentally affect the nature and location of work as well as transport habits at a societal level if it is adopted at a larger scale (e.g. through diminishing of central business districts – layer 3).

To adapt the framework, we applied the universally defined environmental effects of ICT to the specific case of CW [8], [16].

In a second step, we apply the framework to roughly estimate energy impacts associated with the CW living lab in Stockholm. Wherever possible we use actual data collected in the CW living lab.

We (1) collected technical data of the CW space, such as floor space and equipment used, (2) interviewed participants on their everyday life, travel and work patterns, and, (3) collected daily time-use data (time spent on 'travel', 'work', 'everyday chores' and 'leisure'; use of transport modes) for three succeeding weeks by asking participants to fill out time-use diaries.

Data collection took place from September until November 2019. As the living lab is still in operation and data collection is still ongoing, we cannot estimate some effects and in some cases have to use publicly available statistics or make reasonable assumptions.

3 CONCEPTUAL FRAMEWORK OF ENVIRONMENTAL EFFECTS OF CO-WORKING

The framework, which describes direct, indirect and systemic environmental effects of CW, is shown in Fig. 1. The first layer, "Technology: Co-working infrastructure", describes the environmental effects of building, operating and maintaining infrastructures required for CW (e.g. CW space, video conferencing systems, parking places, etc.).

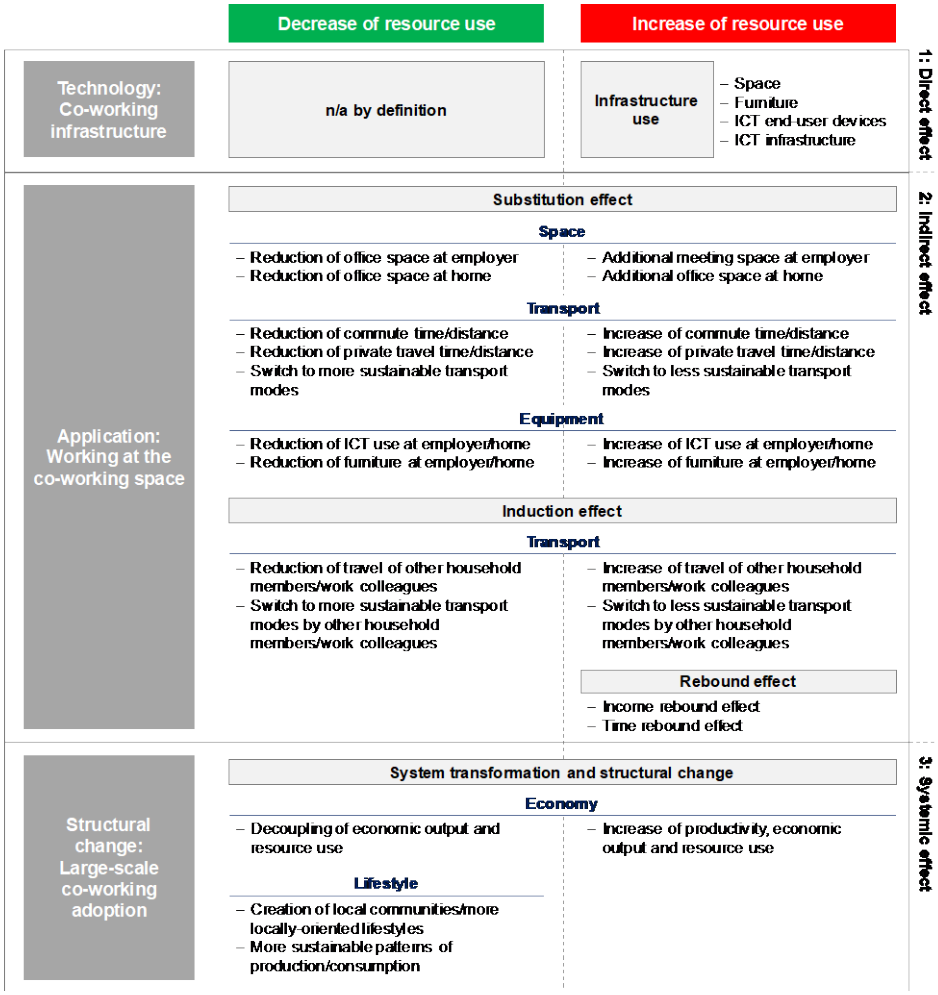


Figure 1: Framework of environmental effects of co-working (based on [8] and [16]).

The second layer, "Application: Working at the co-working space", describes the environmental effects due to individual co-workers or organizations adopting to working at the CW space instead of the employer's office or from home. This directly affects the use of office space, transport infrastructure, and ICT equipment. In addition, behavioral changes, due to changing work and travel practices are possible. For example, employees might spend money and time not spent on commuting on other activities that are associated with their own environmental impacts (patterns known as income and time rebound effects) [20], [21].

The third layer, "Structural change: Large-scale co-working adoption", describes the environmental effects of a system transformation towards CW. It leaves the level of individual co-workers or organizations and focuses on environmental consequences of a transformation towards a society-wide CW culture. This means that factors such as place of residence are decisive for the place of work, regardless of the actual location of the employer. Such a transformation includes changes to working cultures, ways of communication, lifestyles or land use patterns, which only occur if a critical mass of society switches from conventional working habits to CW.

In the following, we describe each layer in some detail. In the framework, we included effects described in literature and observed during operation of the CW living lab. Still, effects beyond the ones we describe can exist.

3.1 Technology layer

Direct environmental effects of building, operating and maintaining CW spaces are by definition unfavorable environmental effects as they all require resources, energy and cause emissions, but do not avoid anything yet. Main environmental impacts associated with building and operating a CW space are caused by facilities (main offices, auxiliary rooms, parking) and equipment (ICT end-user devices and infrastructure, office furniture) (Table 1).

Environmental impacts caused throughout the life cycle of facilities and equipment are caused by the construction of facilities and production of equipment (production phase), the operation of these (use phase) and processes at their end-of-life (EoL phase). As for the production phase, the construction of CW spaces and production of ICT equipment, furniture and other required equipment cause environmental impacts.

With regard to facilities, energy consumption during the operational phase is of great relevance [22] and can be divided into energy for heating, cooling and lighting. Use phase energy demand in office buildings can be estimated proportional to office space [23]. With increasing adoption of energy-efficient building technologies (e.g. improved insulations) the relative importance of the construction phase increases.

With regard to ICT end-user devices, the relevance of the production phase depends on the type of the device, the service life and energy efficiency of the devices. The smaller and more energy efficient the devices, the more important is the production phase [24].

With regard to ICT infrastructure, communication infrastructure (e.g. networks) as well as servers (or data centers) are most relevant. Overall, the total number of equipment used, their production impacts and their energy consumption during operation is decisive for the total environmental impacts.

The main target on this layer is to reduce the relative effects per co-worker that stem from constructing, operating, and maintaining CW facilities and equipment. Amongst others, this means to minimize required CW office space and to aim for high occupancy rates.

3.2 Application layer

The environmental effects resulting from running and using the CW space can work in both directions – reducing and increasing resource use. Main environmental impacts of CW are caused by changes to the process/use of space, transport and office equipment. The main drivers of environmental impacts on this layer are changes to the floor space at the employer's office and the reduction of commuting.

As discussed in the introduction, CW spaces that are close to the employees' homes can contribute to a reduction in commute time and distance. This is the case, if trips to the CW space replace commute trips to work. If working from the CW space replaces working from home, commute time and commute distance increase instead.

Table 1: Facilities and equipment in the co-working space.

Facilities	Main use area	• Workplaces • Meeting rooms • Telephone rooms • Event space
	Auxiliary areas	• Kitchen • Bathrooms • Parking space
Equipment	ICT end-user devices and infrastructure	• End-user devices (screens, printers, white boards) • Infrastructure (e.g. network, servers) • Conferencing equipment
	Office furniture	• Desks • Chairs
	Other	• Coffee machine • Cleaning equipment • …

If, before the adoption of CW, private activities such as library visits, meeting friends or shopping had been combined with commute trips, CW can also induce additional trips. Further, changes in commuting can lead to a change in transport modes used (modal split). For example, for shorter commutes people might consider taking the bike instead of the car. However, people might also increase their use of cars for shorter commute trips, because the opportunity cost of taking the car instead of public transport are less significant (in public transport people can do other activities).

Working from CW spaces has the potential for a reduction of office space at the employer's office and the employee's home (e.g. by implementing desk sharing at the employer's office). However, if these office spaces are not sufficiently reduced, CW can have a net increasing effect on office space due to the CW space. Also, CW might increase demand for meeting space at the employer's office, which is required to communicate with co-workers. Employers adopting CW might also require additional ICT equipment (e.g. for video conferencing).

Furthermore, the saved travel costs can be used for other purposes (income rebound effects) and thus contribute to an increased use of resources [15]. Finally, co-workers can spend saved commute time on other activities that are associated with environmental impacts (time rebound effects [14]).

The main target on this layer is to promote desired and mitigate undesired effects. The effect of CW on (heated) floor space (at the employer and at the co-worker's home), the average change in commute distance of co-workers, thus, the location of the CW space (central, sub-urban, close to the co-workers houses), and the transport modes used, seem to be the most important drivers of the environmental impacts on the application layer.

3.3 Structural change layer

Structural effects of CW are effects that occur if CW is adopted at a larger scale. For example, given that CW reduces time spent commuting and adds flexibility to time and place of work, it may influence families' decisions regarding where to live, jobs, and investments in their dwellings [25], [26]. In the long-term this can also change land-use patterns, e.g. towards "more decentralized and lower-density land use patterns" [27, p. 12]. CW from local CW spaces at a larger scale can also change the nature of work and would reduce demand for major office buildings in business districts, which then could be used for other purposes. Finally, CW can also change traffic streams and demand for transport in general.

Rebound effects occur also on the structural layer. For example, if CW increases the productivity of an industry and stimulates growth; this can lead to an increase in resource consumption and emissions (economy-wide rebound effect) [15], [28].

Structural effects of CW depend on many variables in the broader societal and economic system and are therefore difficult to predict. A long-term CW strategy at a larger scale needs to identify potential structural effects and promote CW schemes that foster environmentally favorable structural effects and mitigate unfavorable ones.

4 CASE STUDY: ENVIRONMENTAL EFFECTS OF A CO-WORKING SPACE IN STOCKHOLM

4.1 Introduction to the co-working space in Stockholm

Situated in Tullinge, a suburb in the south of Stockholm, the CW space is an experimental living lab set up to observe a wide range of effects of having a workplace close to the home of the participants. The CW space integrates various accessibility and mobility services to participants that allow them to book, plan, and travel. It offers an activity-based workplace close to co-workers' homes, gives access to 3 electric bikes (2 electric bicycles and 1 electric cargo bicycle) for free and a peer-to-peer carpooling scheme.

It is equipped with 14 workplaces, which can be booked via an online application, a well-equipped conference room for eight people, as well as three rooms for telephone or video calls. This experimental CW space acts as a platform to bring together a range of actors such as citizens, researchers, business and public authorities to create, validate, and test new mobility and accessibility technologies and services in a real-life context. The CW space has been in operation since January 2019 and as of February 2020 44 out of 60 participants regularly work there.

4.2 Co-working impacts on time-use and travel

We used the results of the time-use diaries of 20 co-workers who work for an IT company in Kista, north of Stockholm to compare their daily time-use including travel. Because living close to the CW space in the south of Stockholm was a requirement for participating, these co-workers significantly reduced their commute time and distance on CW days compared to employer office days. We compare time spent on 'travel', 'work', 'everyday chores' and 'leisure' on days, when people work from the employer's office, from the CW space or from home (Fig. 2).

We also compared the (share of) time people spent in different transport modes on these days (Fig. 3). We did not consider days, when people worked from other locations or from several locations on one day. We also excluded low quality data entries and untypical work days (work time lower than 4h; total recorded time lower than 8h; time difference between the recorded time spent on 'travel' and recorded time in specific transport modes is higher than 100 min; these were two separate questions). This results in time-use data from 244 workdays.

4.2.1 Time spent on activities

Of all diary days, 56% are employer office days, 17% CW days, 12% home office days and 15% other types of workdays (e.g. various work locations).

Average 'travel' time is highest, when people work from the employer's office (133 min) and decreases by 68 min on CW days and 104 min on home office days. Average working time is also slightly higher on days, when people work from the employer's office (523 min) and marginally lower on home office (-6 min) and CW days (-14 min). One possible explanation for slight differences in work time is that on home office or CW days employees spend less time socializing with work colleagues who are not physically present.

Average time spent on 'everyday chores' and 'leisure' is highest on home office days and lower on days when people work from the employer's office or the CW space. Differences in time spent on other activities (e.g. sleep) are also possible, but were not collected in the time-use diaries.

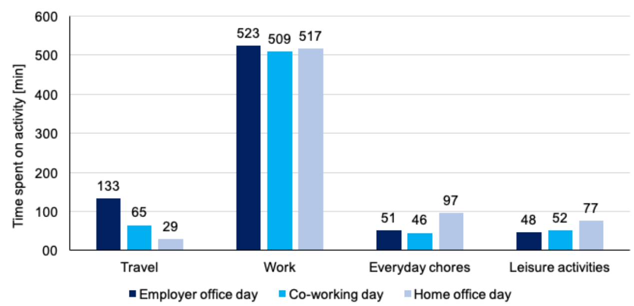
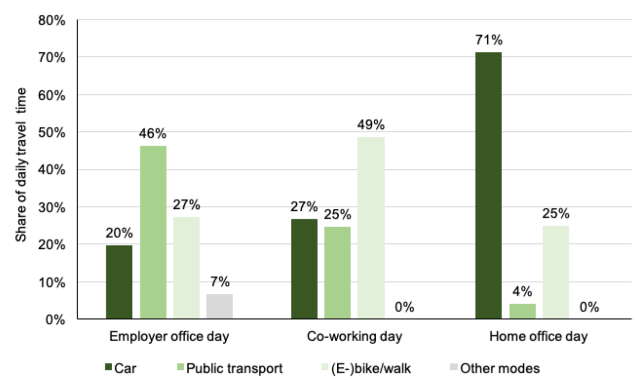


Figure 2: Average time spent on an activity by work location on that day.



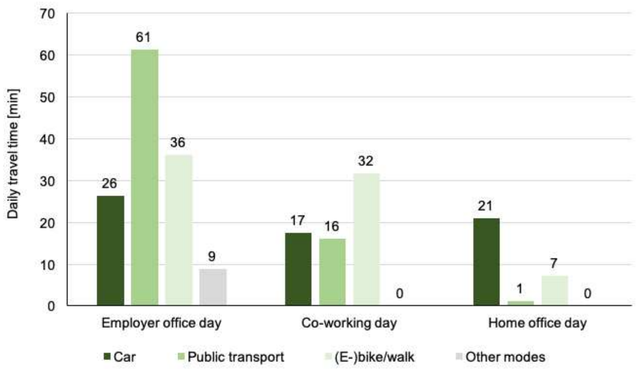


Figure 3: Average share of travel time (top) and average absolute time (bottom) spent in different transport modes by work location on that day (other modes are for example boats).

4.2.2 Used transport modes (modal split)

On employer office days, average time spent in public transport is highest (61 min) and significantly lower on CW days (16 min) and is close to zero on home office days.

Average time spent travelling by car is also highest on employer office days (26 min) and slightly lower on CW days (17 min). Interestingly, on home office days, co-workers spend on average more time in car transport (21 min) than on CW days. One explanation for this could be that individuals shift activities which induce car transport to home office days (e.g. going shopping)

Average time spent (e-) biking and walking is of the same order of magnitude on employer office and CW days and significantly lower on home office days.

In the interviews, we asked participants about their commute transport modes specifically. The results indicate that public transport is the preferred commute transport mode, followed by car transport. This confirms the patterns observed in the time-use data.

Interviews also showed that biking and walking is rather done for private purposes. This is one possible explanation why no large differences in average time spent on biking or walking can be observed between employer office and CW days; however, on home office days, average time spent biking or walking is comparatively low. This could indicate, that that bike or foot travel is somehow related to work routines outside the home (potentially due to walking or biking between home, public transport stops and the office). Thus, further research is required to investigate this relationship.

4.3 Energy impacts

In the following we apply the framework of environmental effects of CW to roughly estimate energy impacts of the CW living lab.

4.3.1 Estimation approach

We estimate energy requirements associated with…

- heating, cooling and lighting of the CW space (direct effect),
- ICT equipment operated in the CW space (direct effect), and,
- changes in travel time (indirect effect), on employer office, CW and home office days.

Due to lack of data, we do not consider furniture or changes in space use at home or the employer office; neither effects on behavior of other household members or work colleagues (e.g. changes in travel) nor systemic effects. To some extent, changes in travel time include income and time rebound effect, as people spend saved commuting cost and time on travel for other purposes.

All calculations are performed for one CW day of one co-worker. Calculations focus on the use phase (energy requirements associated with the operation of the CW space and fuel consumption for transport). Energy impacts associated with production of goods and services (e.g. production of cars, construction of office buildings, and production of ICT equipment) are out of scope.

4.3.2 Inventory data.

Table 2 provides an overview of data on floor area, ICT equipment and the number of people working in the CW space.

To estimate energy impacts of heating, cooling and lighting of office space we used the floor space of the CW space and yearly energy requirements of standard office buildings according to the "Institut Wohnen und Umwelt" [23],[29]. We divided energy impacts of heating, cooling and lighting of office space by the number of people working in the CW space and the number of workdays per year to estimate impacts per co-worker and CW day. Thereby, we assume that co-workers who work for other companies have the same CW patterns (number of CW days) as the co-workers working for the IT Company in Kista.

For operation of ICT equipment, we used the number of devices in operation in the CW space and daily device energy requirements according to ecoinvent [30]. To estimate impacts per co-worker and CW day, we divided ICT equipment energy consumption by the number of workplaces at the CW space. We did not include network devices and one videoconferencing system due to lack of data.

To estimate energy impacts of changes in travel time, we used the results of the time-use diaries (Fig. 2, Fig. 3), direct energy requirements of fuel consumption and provisioning of travel modes according to mobitool [31] and average speed of transport modes [32]. We needed to estimate the distances driving with each transport mode using average speed of transport modes, because in the travel diaries co-workers recorded the time spent in transport modes.

4.3.3 Estimation results.

Fig. 4 shows the estimated average difference in energy consumption between one person working from the CW space for one day, the employer's office or home. It shows that much energy consumption is caused by heating, cooling and lighting (mainly heating and lighting, only few cooling) of CW office space (24.0 MJ) and only few energy consumptions is caused by operation of ICT equipment (2.0 MJ).

Table 2: Co-working space floor area, amount of ICT equipment used in the co-working space and number of co-workers.

Building	Floor area co-working space [m2]	170
ICT equipment	Number of workplaces	14
	Number of screens	18
	Number of desktop computers	1
	Number of printers	1
	Number of TV sets	1
Co-workers	Number of co-workers regularly working in the co-working space	44
	Number of co-workers from IT-company in Kista for whom time-use diaries are available	20

Compared to employer office days, average reduction in travel leads to a reduction of travel-related energy impacts of 22.5 MJ; thus, energy impacts of reduction in travel and energy required for heating, cooling and lighting of office space roughly cancel each other out. Compared to home office days, co-workers spend on average more time travelling on CW days; still travel-related energy consumption is slightly lower. This is because on home office days, people use the car on average more than on CW days. However, travel-related energy savings on CW days compared to home office days are much lower than the energy required to operate the CW space. The total energy required for heating, cooling and lighting the CW space does not increase proportionally with increasing utilization of the CW space. That is, because buildings do not require much more heating energy if occupancy increases or vice versa. However, the number of avoided employer office days (long commute) is proportional to total commute-related energy savings (e.g. one CW or home office day avoids one long commute, two CW or home office days avoid two long commutes,…). Thus, substituting additional employer office days with CW or home office days is a good strategy to increase travel-related energy savings.

When interpreting the results, we have to consider that this estimation did not consider changes in energy consumption at home or at the employer's office. It is plausible to assume a decrease in these energy requirements, leading to additional energy savings through CW. However, income and other rebound effects could compensate for the savings.

We also did not consider interdependencies between weekdays and weekends, because only few diarists carefully filled out time-use diaries on weekends. In principle, CW can also impact time-use on weekends. For example, people could systematically shift activities for which they require the car (e.g. shopping) from weekends to home office days. This would reduce the car use on weekends, but total car use per week would not change.

5 DISCUSSION AND CONCLUSION

CW from a local CW space is a promising ICT use case to reduce transport demand and associated environmental impacts, while having a positive effect on well-being of employees (e.g. more time for family and friends). However, CW also causes environmental impacts, for example through infrastructure required to operate CW spaces or through time rebound effects.

Based on an existing framework of environmental effects of ICT, we developed a conceptual framework of environmental effects of CW. The framework distinguishes environmental effects of CW on three layers: (1) direct effects through the infrastructure required to operate CW spaces, (2) indirect effects due to individual co-workers or organizations adopting CW (e.g. avoided commutes), and, (3) structural effects through a system transformation towards CW (e.g. fundamental changes in demand for transport and office space).

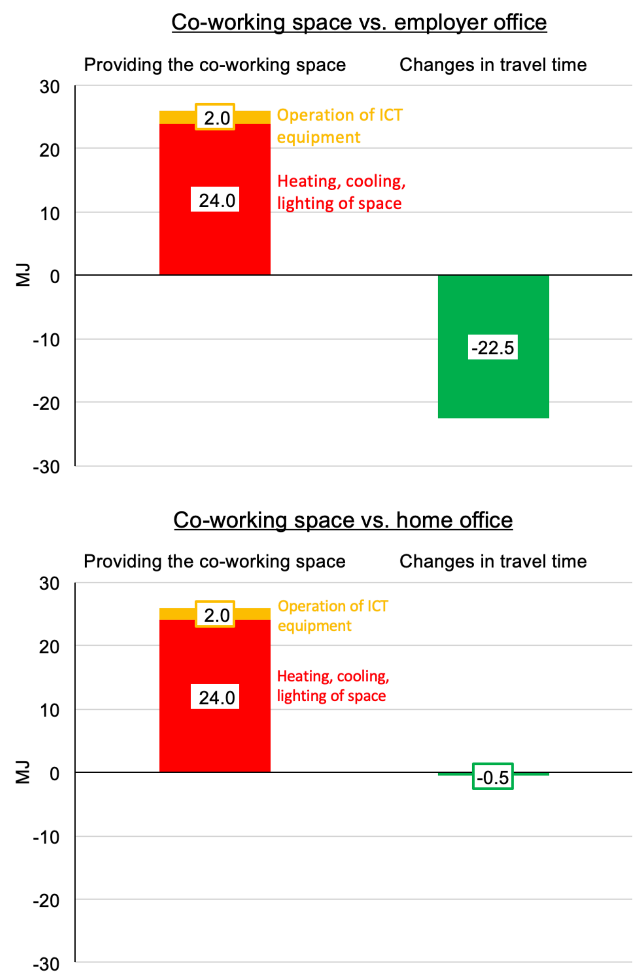


Figure 4: Difference in average energy requirements on a co-working day compared to a workday at the employers' office (top) or at home (bottom) across co-workers.

While direct effects are environmentally unfavorable by definition (they increase resource use), indirect effects and systemic effects can increase but also reduce resource use (e.g. by avoiding commute time or inducing additional travel for other purposes). Thus, net environmental effects depend on the magnitude of effects on all three layers and institutions should consider them when developing and adopting CW schemes.

In our case study of a CW living lab in Stockholm, we found that co-workers on average travelled most on employer office days, less on CW days and least when they worked from home, leading to travel-related energy savings. However, changes in travel mode can counterbalance this effect, as we found in our case study: On home office days, participants spent on average more time travelling by car than on CW days, leading to higher travel-related energy use on home office days than on CW days.

A rough estimation shows that the energy required to operate the CW space and travel-related energy savings roughly counterbalance each other on employer office and CW days. Thus, CW does not lead to energy savings per se, but should be accompanied by additional energy savings measures, such as reduction of office space at the employer's office. One way to reduce employer office space is to, instead of having fixed workplaces, adopt shared workplaces which can be booked by employees for days when they work from the employer's office. This can increase the utilization of workplaces at employer offices and allow for reduction of total office space; however, in companies with traditional work environments a transformation of working culture, tools and regulations as well as support for employees who struggle with such a change might be required. Other companies (e.g. start-ups) might not even rent or build larger office spaces and establish CW in the first place.

The main levers to realize energy savings through CW are a reduction of total travel time and distances (e.g. by choosing CW spaces close to home), use of sustainable transport modes, a net reduction of (heated) floor space (at the CW space, at the employer's office and the co-workers home) and a high number of CW or home office days (increasing the number of avoided commutes to employer offices).

Our calculations have limitations and uncertainties regarding the extent of daily activities captured, the energy requirements of travel and buildings, and the consideration of structural effects. We focused on operational energy requirements, thus environmental effects related to the production, construction and disposal of buildings, devices, vehicles and roads are not included in our estimation.

The co-workers investigated in this case study all work for the same IT Company. Thus, the possibility to adopt CW and behavioral changes of individuals through CW can be different for individuals working for different companies, in different sectors with different job requirements. Calculations are based on averages across all co-workers. Investigating individual co-workers can reveal further insights on changes in time-use patterns which depend on characteristics of individuals (e.g. preferred commute pattern). We also excluded weekends, because time-use diaries of weekends are of lower quality than of workdays. Thus, we could not assess associations between CW patterns, time use on weekends and total weekly travel.

Furthermore, we presented our results in terms of energy impacts of adopting CW. Environmental impacts beyond energy use (e.g. global warming potential or human toxicity) exist and need to be investigated to provide a full picture.

Finally, we did not collect time-use data of participants before they adopted CW. Thus, whether CW leads to a net reduction in travel cannot be assessed with the available data. Still, the calculation demonstrates, that CW does not necessarily lead to energy savings and that non-travel related environmental impacts of CW matter.

Future research should take a broader perspective in terms of effects and activities included in the calculations and environmental impact categories and life cycle stages considered. If CW is adopted at a larger scale, systemic effects can lead to fundamental transformation of transport systems and land use. These effects are difficult to estimate and further research is required. We encourage companies and researchers to experiment with CW and find ways to use CW for reducing environmental effects of transport, work and everyday life. The framework developed in this paper and the findings of the living lab can provide guidance for this.

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